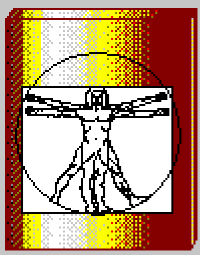
Chapter 1
HUMAN FACTORS

1 Human Factors



Author: Michael E. Maddox

Quote: " We have come to understand many of the factors that contribute to human error... With good human factors design and testing techniques, the effects of many sources of human error can be controlled. "

INTRODUCTION

Aviation maintenance has changed over the years.[1] Newer aircraft contain materials, power plants, and electronic subsystems that did not exist in earlier models, and the number of older aircraft has increased. Technicians use more and more sophisticated equipment and procedures. One aspect of aviation maintenance that hasn't changed, however, is that most maintenance tasks are still done by human technicians and inspectors.

While the aircraft on which they work have evolved dramatically over the last 50 years, maintenance workers still exhibit all of the capabilities, limitations, and idiosyncrasies that are part of being human. The addition of new materials and electronic systems has *not* meant a reduction in the workload or required skill set for maintenance supervisors and technicians. Because of the blend of aircraft in commercial fleets, aviation maintenance workers must maintain the skills and knowledge required to keep a wide variety of both new and old aircraft flying.

As you consider the jobs of aviation maintenance professionals, consider also the broad range of required skills, the pressures of keeping all aircraft in revenue service, the pressures of working during evening hours under severe time constraints, the safety implications of maintaining an aging fleet, the increased uncertainty of job security, and other factors known to affect human performance. Aviation maintenance workers' jobs have become complex and stressful.

The discipline of Human Factors began in the aviation industry and has matured along with it. Most of the research and practical work of human factors professionals has been related to the *design* of systems and products. Regardless of the domain in which they are applied, human factors methods are always aimed at ensuring the safety and efficient performance of humans in human-machine systems. This *Guide* is not aimed at professional human factors practitioners. Rather, our goal is to provide non-practitioners with enough information to allow them to recognize and take into account human capabilities and limitations. Therefore, the guidance we provide relates more to *analysis* and *evaluation* than to design.

This chapter describes some of the fundamental concepts in the field of Human Factors and how you can use the knowledge gained during the past five decades to help aviation maintenance supervisors and technicians perform their jobs with more efficiency, more safety, and less stress.

BACKGROUND

The field of human factors has its roots firmly planted in aviation. The first identifiable work in the area of equipment design and human performance was done during World War II.[2] This work was concerned primarily with eliminating certain accidents related to cockpit design and aircrew performance. In fact, much of the pioneering work related to equipment design, training, human performance under stress, vigilance, and other topics was conducted and published in the period following the war.

Prior to the war-related research, most people held a fairly simplistic view of how people interacted with their environment. The idea of humans as infinitely "flexible" seemed to guide most design. It soon became apparent, however, that human users' interaction with their jobs and equipment is much more complex than we thought. In addition to the size, shape, and placement of controls and displays, other, mostly psychological, elements were found to affect human performance.

The field of human factors was recognized in the United States in 1957, with the founding and first meeting of the Human Factors Society. In Europe, a parallel professional field, known there as Ergonomics, was developing during the same period. In England, the Ergonomics Research Society, now called The Ergonomics Society, was formed in 1949.[3] Human factors practitioners first concerned themselves with elements of human performance that included at least some psychological component. Ergonomics concentrated more on the biomechanical and biophysical aspects of work.

The original distinction between ergonomics (the word's Greek roots mean "the study of work") and human factors has gradually disappeared. The distinction was officially removed recently when the Human Factors Society changed its name to the Human Factors and Ergonomics Society. In this *Guide*, the terms "human factors" and "ergonomics" are used interchangeably.

Most of the human factors research directed toward the aviation industry, at least until the past few years, has been aimed primarily at cockpit and flight crew issues.[4,5,6] However, it is now apparent that the public's safety rests on the proper conduct of three sets of activities: design, operation, and maintenance.

Because of a series of in-flight mishaps, the Congress and the Federal Aviation Administration (FAA) have focused on the design of maintenance tasks, equipment, and training. Perhaps the most famous mishap occurred in 1988, when an Aloha Airlines B737-200 suffered structural fuselage failure and subsequent decompression (see Figure 1-1). The National Transportation Safety Board (NTSB) conducted an investigation of this accident and cited several human factors issues associated with older aircraft.[7]

As a direct result of the Aloha Airlines accident, the FAA convened an International Conference on Aging Aircraft in June, 1988. After the second such conference, a leading FAA researcher noted that "the more we looked at problems in maintenance operations, and particularly those of aging aircraft, the more we saw human factors as some part of the problem."[8]

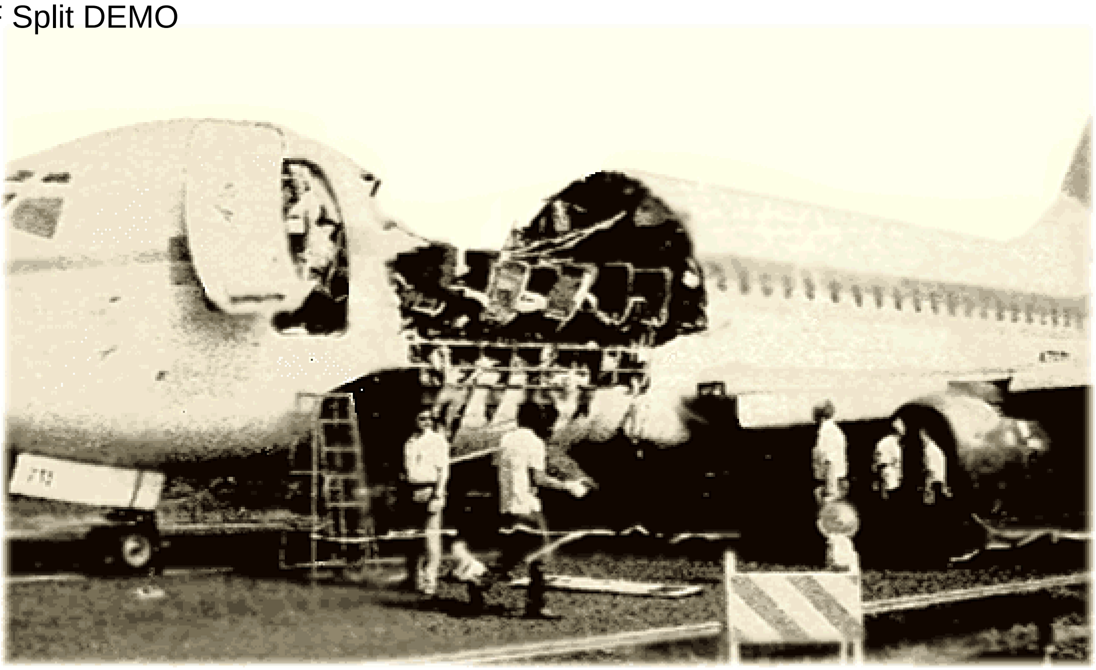


Figure 1-1. Forward fuselage of B-737 following inflight structural failure (NTSB).

This sentiment was echoed by Congressman James Oberstar when he posed several rhetorical, but practical, questions:

> What can be done about the fact that rivet inspection is boring, tedious, mind-bending work, susceptible to human error? How do we ensure that the means established to communicate with each other are, in fact, effective and that the right information is finding its way to the right people at the right time? How do we know whether training of inspectors and mechanics is all it needs to be? And how do we ensure that it will be?
>
> All of these and other human factors [issues] are tough ones, difficult to attack because we are dealing with human beings who don't perform according to mathematical models. But the FAA and the industry have to attack [these human factors issues] with the same vigor that the task forces have addressed to the other technological problems of aging aircraft.

Certain aging aircraft mishaps have provided the impetus to examine human factors issues, but these issues relate to *all* types of aviation maintenance, not just to the older part of the fleet. In fact, many human factors guidelines that apply to other types of industries, for example in workplace design, job safety, and facility design, also apply to aviation maintenance

The FAA Office of Aviation Medicine (AAM) has been assigned responsibility for developing and managing a research program related to human factors in aircraft maintenance and inspection. This program has addressed a number of aviation maintenance issues. This *Guide* is one of the products of the AAM human factors research program.

ISSUES AND PROBLEMS

There are many issues associated with the human factors aspects of aviation maintenance. These issues can usually be placed into one or more the following broadly-drawn categories: effective and efficient training for technicians and inspectors, on-the-job safety of maintenance workers, reducing human errors that compromise public safety, and reducing the overall cost of maintenance.

Training

The general topic of training is addressed in detail in Chapter 7. However, it's worth noting here that there are many human factors issues that directly affect how easy or how difficult it is to learn certain maintenance-related skills. The FAA sets minimum curriculum and performance requirements for aviation maintenance technicians and inspectors. Certain aspects of the systems to be maintained, the technicians' job and workplace, and the tools they use to do their job affect how long it takes them to become proficient at their tasks and how likely it is that they will commit errors.

Worker Safety

Numerous studies and statistical reports show that the workplace can be dangerous.[9] This is especially true for work environments with heavy parts being moved about, with rotating machinery, with toxic or hazardous materials, and with work locations that are above the ground. All those factors are present in aviation maintenance shops. The study of human factors has made significant general contributions to workplace safety. Much of this work is directly applicable to the aviation maintenance workplace.

Public Safety

The ultimate fear of any maintenance supervisor, technician, or inspector is that an error, once committed, will remain undiscovered and ultimately lead to an accident. The vast body of human factors research shows the certainty that human beings will commit errors. The saying that "to err is human" has a sound scientific basis. Studies have shown that the proportion of accidents caused by human error is in the 60-80% range, *not including design errors*.[10,11,12]

Over the last 50 years, we have come to understand many of the factors that contribute to human error. We are able to control some of these through design, training, procedures, and inspection techniques. When control is combined with good human factors design and testing techniques, the effects of many sources of human error can be controlled.

Cost

There is a tendency on the part of management to see any type of analysis or evaluation as an "extra-cost" program. Human factors practitioners have always maintained that the small incremental amount of time and money required to practice user-centered design is more than returned in added productivity and safety. The general goal of all human factors design is to provide a safe and efficient working environment. A number of recent studies of the cost-effectiveness of the human factors approach have shown that the user-centric approach to design and operation is indeed much less costly than the alternatives.13,14,15 Therefore, human factors should be viewed as a reasonable cost-reduction approach to aviation management.

REGULATORY REQUIREMENTS

The Federal Aviation Regulations (FARs), which comprise Title 14 of the Code of Federal Regulations (CFR) do not presently contain explicit human factors requirements. Certain regulations related to maintenance "performance", such as Parts 43.13 and 43.15, Part 121-Subpart L, and Part 135-Subpart J, are obviously based on human factors types of considerations. However, they do not invoke specific human factors guidelines or standards.

Although the FARs do not specifically address human factors requirements, there are presently two sources of regulatory requirements directly related to human factors in aviation maintenance. The first is the set of regulations that compose the Occupational Safety and Health Administration (OSHA) requirements. OSHA regulations are contained in the Code of Federal Regulations (CFR), Title 29, Parts 1900 to 1910.[16] Only a small fraction of these regulations are directly related to human factors issues. Applicable sections of the OSHA regulations are cited in appropriate chapters of this *Guide*.

The second source of human factors-related regulatory requirements is the Americans with Disabilities Act (ADA).[17] This legislation mandates, among other things, that all employers must make "reasonable accommodations" for disabled workers. There are other implications of the ADA. For example, the processes of personnel selection and job assignment are directly affected by ADA provisions. Again, the relevant parts of the ADA are cited as appropriate in this *Guide*.

As this *Guide* is being written, there are at least two potential regulatory initiatives underway. The first is being done by an American National Standards Institute (ANSI) committee developing ergonomic guidelines for industry. This committee is known as Z-365 and is placing its emphasis on preventing cumulative trauma disorders (CTDs). The committee has already developed a draft of its proposed standard (or guideline-it's not clear which it is to be at this point). The Z-365 draft includes a set of screening criteria that can be used to identify tasks that place workers at risk for CTDs[18]

While the ANSI work is interesting, it is unclear whether it will result in any binding regulations for the airline industry. The second activity will definitely result in at least some human factors regulation of all industries under the purview of the Occupational Safety and Health Administration (OSHA). Federal and state OSHA programs are presently developing ergonomic standards that their inspectors will use.

After a number of court challenges, some of which are still in process, the California Occupational Safety and Health Standards Board has approved a repetitive motion injury (RMI) standard that requires employers to implement an ergonomic program to minimize such injuries.[19] Whatever the outcome of the various reviews still to be done, it is clear that all OSHA-regulated industries will be subject to at least some new ergonomic guidelines.

CONCEPTS

Basic human factors concepts apply to the aviation maintenance domain. In fact, human factors practitioners would argue that such concepts are so fundamental that they apply to all situations in which humans interact with other system components. Becoming comfortable with these concepts allows you easily to understand the reasons for the guidelines that are provided throughout the remainder of this *Guide*.

Detection and Perception

As humans, we interact with our environment by acquiring information, processing it, and then taking certain actions. We use various senses to gather the information we need. The five basic senses are vision, audition, touch, olfaction (smell), and gustation (taste). In addition, there are several other senses we use to acquire information. Our vestibular sense allows us to detect balance, motion, and acceleration. Our proprioceptive sense tells us the position and location of our limbs, and our kinesthetic sense tells us how we are moving various parts of our body. Disregarding any possible psychic powers, if we can't detect something with one or more of our senses, we usually aren't aware of its presence.

As a result of a vast amount of sensory research, we know several facts regarding perception.[20,21] First, we know the minimum levels of stimuli needed for detection by each of our senses. These are called "threshold values" for detection. We also know generally how many different, distinct levels of a particular stimulus humans can distinguish.

We know that there is a difference between detection and perception. *Detection* refers to the physical response of our senses, or detectors, in the presence of some event or stimulus. *Perception* refers to the combination of psychological and physical (called *psychophysical*) processes that allow us to know that we've detected something. It is possible, even likely, under certain conditions, that we will not perceive an event, even one well above the threshold level for detection. This fact cannot be doubted by anyone who has been married and accused of never hearing anything one's spouse says.

We know that certain environmental characteristics affect our ability to perceive certain events. Physical and psychological stress, attention demands, heavy workload, and other conditions common in the aviation maintenance environment can cause a loss of perceptual capabilities.

Early and Frequent Testing

In many areas of business and technology, a frequent requirement is to "Get it right the first time!" Actually, it's almost *never* right the first time, regardless of what "it" is. Even in technical fields with a precise and formal base of knowledge, such as Electrical Engineering, new systems are always tested and refined prior to being placed in service. Human factors is no different from other fields in this respect; however, humans are much more unpredictable than mechanical or electrical components.

Human factors practitioners know that there is a lot of uncertainty related to human behavior. To account for this, we place a fundamental emphasis on testing throughout the design process.[22] We attempt to involve end users as early in the process as possible and continue to solicit user input even after a product is put in service. This isn't altogether different from the way new aircraft systems are designed and built. An airframe manufacturer doesn't wait until a new aircraft is completely built before testing its components. Likewise, the human factors approach requires early and frequent testing of major system components, including its users.

Errors

One essential fact of human nature is that people commit errors. This tendency to commit errors is so pronounced and widespread that we simply assume that errors will occur. From a human factors perspective, there is no such thing as error-free operation by humans. Researchers have been fascinated by the nature of human errors.[23,24] Names have been given to different types of errors, e.g., a "slip" is different from a "mistake."

Various theories have been advanced to explain the causes of different types of errors. Certain types of errors are caused by simple physical incompatibilities. For example, printed characters are confused when they are too small. Other types of errors are caused by complex psychological factors. Still other errors are caused by certain types of stress such as fatigue or severe time limits.

Fortunately, we know a lot about what causes errors and how to design systems that minimize the likelihood of certain types of errors. The important point is that regardless of the precautions we take, errors will occur. If we depend on error-free human performance, our system eventually will fail. For errors we cannot avoid, we must design system elements so as to minimize their effects.

Habituation

We often hear that people are extremely adaptable. That is, we can get used to pretty much anything, given enough time. If we see, hear, feel, smell, or taste the same stimulus frequently or continuously, our response to it gradually decreases.[25] Eventually, the stimulus arouses no perceptible response. When this happens, we have "habituated" to the stimulus.

Habituation occurs both physically and psychologically. Physically, a constant stimulus becomes imperceptible. For example, we don't feel our wedding ring or watch after we've worn them for a long time. Likewise, we habituate to more complex situations. If a job task is particularly hazardous, we're likely to be very careful the first few (or few hundred) times we perform it. Eventually, however, we will habituate to the danger and then must constantly remind ourselves to be careful.

Habituation is a useful coping mechanism for living in the real world. It serves to filter the stimuli that are constantly bombarding us. However, in the aviation maintenance environment, habituation allows us to adapt to dangerous or noxious environments and to ignore potentially dangerous indicators.

Human Capabilities and Limitations

Perhaps the most fundamental human factors concept is that people have certain capabilities and limitations that must be considered when designing or evaluating systems that include humans. In other engineering disciplines, it is commonly understood that system components have a range of performance capability. For example, the rivets used to attach aluminum skin to a fuselage can withstand forces that act to pull them apart. Everyone agrees that these rivets will eventually fail if enough force is applied to them. While the precise range of human capabilities and limitations might not be as well-known as the performance range of mechanical or electrical components, the same principles apply.

Unlike mechanical components, humans rarely suffer catastrophic failures. It is certainly possible to apply enough force to tear muscles and break bones. More frequently, however, exceeding human capabilities results in subtle consequences, such as increased errors, inability to attend to all of the tasks at hand, poor judgment, etc. Also unlike inanimate components, human performance is affected by social, emotional, cognitive, and psychological elements. Since human performance tends to be more variable than that of non-human system components, we must take care to provide adequate design margins for human operators.

Performance Shaping Factor

This term, usually called by its acronym PSF, was introduced in the late 1960's to help conceptually frame the idea of human reliability.[26] In its most general meaning, a PSF is anything that can affect human performance. Theoretically, PSFs can have either a positive or negative effect on human performance. However, discussion of PSFs is often limited to those elements that adversely affect performance. For example, poor training is a PSF that is known to increase errors.

PSFs are usually categorized as either *internal* or *external*. External PSFs are outside the individual worker or user, usually some characteristic of the workplace, the task, or the organization. Internal PSFs come from within the person and are typically related to skills, stress, or other physiological, psychological, or social element. Typical examples of external PSFs are poor workspace layout, adverse environmental conditions, inadequate training, poorly designed tools, etc.[27] Common internal PSFs are high stress, a disruptive social environment, and low skill.

Anything that causes human performance levels to increase or decrease can be considered a PSF and thus subject to analysis and mitigation using human factors techniques. This is true even for topics not traditionally considered within the scope of human factors, such as sexual harassment, substance abuse, etc. At least one study has shown that stress like that caused by such emotional factors can increase the probability of human error by a factor of 2 to 5.[28]

Physical Compatibility

People come in myriad shapes, sizes, and physical conditions. Human factors professionals have recognized and studied this.[29] It turns out that a seemingly simple idea isn't simple at all when we have to consider this range of human variation in the design of hardware and workplaces. The three elements most closely related to the concept of physical compatibility are anthropometry, biomechanics, and work physiology.

Anthropometry

The study of human body dimensions is known as *anthropometry*. Many anthropometric studies, generally conducted by the military, have produced tabled values of various body dimensions.[30,31] These studies typically have measured certain body dimensions of many individuals and then reported results in terms of gender and "percentiles" within each gender. For example, a tabled value for the dimension "seated eye height" for a 75th percentile male is interpreted to mean that 75% of all males in the population have a seated eye height **lower** than this value.

Several aspects of anthropometry are worth noting. First, women tend to be smaller than men. This probably isn't a big surprise, but it has profound implications for design. In general, we try to design to accommodate the 5th through the 95th percentiles for human workers. For example, if we're interested in standing height, we have to design to accommodate a range from the 5th percentile *female* to the 95th percentile *male*.

Second, there is a common, incorrect tendency to interpret percentiles in terms of averages. If one were to design a product for the 50th percentile of a particular dimension, *half* the potential user population would probably have difficulty using it.

Third, people tend not to fall into the same percentile for multiple body dimensions. People with small hands don't necessarily also have short legs. This fact isn't obvious, but it has been found to be true over thousands of measurements. If we designed for the 5th through 95th percentiles, we would expect to exclude only 10% of the population. However, one study found that by imposing such limits on 13 body dimensions, *52 percent* of the population was excluded. The idea that any particular individual will fall into the same percentile for all body dimensions is often called the "myth of the average person."

Biomechanics

Maintenance tasks typically involve doing, as well as thinking about, something. Human workers use various body parts to manipulate elements of the work environment. The science of Biomechanics addresses issues of movement, leverage, and strength.[32] From a biomechanical perspective, the human body is a series of physical links (bones) connected at certain points (joints) that allow various movements.

Muscles and tendons provide the motive force for all movements. The force that can be applied in any given posture is dependent on the strength available from muscles and the mechanical advantage provided by the relative positions of the load, muscle connections, and joints.

While Biomechanics is an independent field of study, human factors practitioners often use its principles to analyze work tasks. There is a large body of information related to strength available in various postures, to the range of motion for each major joint in the body, and to strength and motion differences between males and females. Biomechanical effects largely determine our ability to perform certain tasks and our risk of specific types of injuries.

Work Physiology

Most human work tends to be distributed over time rather than lumped into discrete actions. The physical sciences define *work* as the application of force over some distance. The science of Work Physiology studies the type, amount, rate, and duration of human workers' energy expenditure. As with Biomechanics, Work Physiology is an independent discipline. Human factors practitioners use certain principles from work physiology to assess the physical work environment and the design of jobs and tasks.[33]

People vary in the strength they can bring to bear on a task; they also differ in their capacities to perform different types of work over time. Many studies have attempted to describe the acceptable range of energy usage over different periods of time and in different environments. As with other basic physical variables, one's ability to perform work is affected by a number of different factors.

Stereotypical Behavior

As we grow up in a particular culture, we learn to do things in a certain way. Since we see that things work in a particular way over a long period, we develop expectations that they will always work that way. When we want to turn on a light from a wall switch, we flip the switch up. When we see a red light or sign on the highway, we interpret that as a requirement to stop or as a sign of danger. Such overlearned associations are known as *cultural stereotypes*. Behavior associated with cultural stereotypes is called *stereotypical behavior*.[34]

Stereotypical behavior is important in human factors. When a task or control works as one expects, it "conforms to stereotype." When it doesn't, it "violates stereotype."[35] The more a task or tool incorporates stereotypes, the easier it is to learn. Since we've already learned stereotypical behavior, we don't have to learn it again.

There are two important aspects of stereotypical behavior. First, such behavior is culture- specific. In most of Europe, light switches have to be moved down to turn a light on. In China, the color red is associated with happiness, not danger. Also, we don't think about our stereotypical behaviors. They are so ingrained that we just do them when the proper stimulus occurs.

This is worth noting, since we tend to revert to stereotypical behavior in the presence of stress or lack of attention. A good example of such reversion is that for one used to driving on the right side of road it is quite easy to make a transition to right-hand drive automobiles and to driving in the left lane. In a high-stress situation, such as making an avoidance maneuver, the same person will inevitably take actions appropriate for a left-hand drive car.

In London, arrows painted on sidewalks at certain street crossings direct non-British pedestrians to look to the right before crossing the street. Although we know that people drive on the left in England, our stereotypical behavior is to look to the left before crossing the street. This could be a serious mistake in a place where traffic generally approaches from the right.

Stress

Another seemingly simple concept is that of *stress*. Through experience, we've learned that certain events or conditions cause us to feel stress. However, like workload, stress is a difficult concept to quantify. Also, like workload, stress is usually defined in terms of its effects on performance.[36] In the human factors world, stress is a very general idea. Many events or conditions produce measurable decreases in performance. Events and conditions that cause stress are called *stressors*.

Two aspects of stressors are important to understand both for their broad range and for their effects on individuals. Stressors can be physical, environmental, task-related, organizational, or psychological. Examples of stressors include injury, fatigue, heat, cold, time pressure, workload, personality conflicts, family problems, and substance abuse.[37] Just about anything that affects the way we live and work can act as a stressor.

The effects of stressors vary greatly from person to person. A condition that causes great stress in one person might cause no stress in another. Whether a particular stressor causes stress can sometimes be predicted. For example, a person's overall physical condition is a good predictor of whether aerobic work will cause undue stress. However, stress is often a product of a number of interacting factors.

As with workload, stress is measured by its effects. There are some objectively measurable physical effects of stress, such as elevated blood pressure, increased perspiration, etc. However, these effects don't always accompany stress. Stress is usually inferred by a decrease in task performance.

In the aviation maintenance environment, there are many identifiable stressors.[38] Fatigue caused by working at night and time pressure to get aircraft back into revenue service are two obvious conditions almost certain to cause stress. In stressful circumstances, it is very important that jobs, workplaces, work schedules, tools, facilities, and procedures incorporate human factors principles.

Systems Approach

The basis of any human factors approach is to consider human workers as part of an integrated system that includes hardware, software, facilities, tools, and the overall work environment.[39] One depiction of this systems approach is known as the SHEL model (see Figure 1-2).[40]

The initials of the acronym SHEL stand for software, hardware, environment, and liveware. In this model, software is composed of rules, procedures, customs, and other elements that determine how the system operates. Hardware is composed of any non-person, physical entity such as buildings, vehicles, test equipment, etc. Liveware consists of people. The environment consists of the physical, political, organizational, and economic framework in which the other system elements interact.

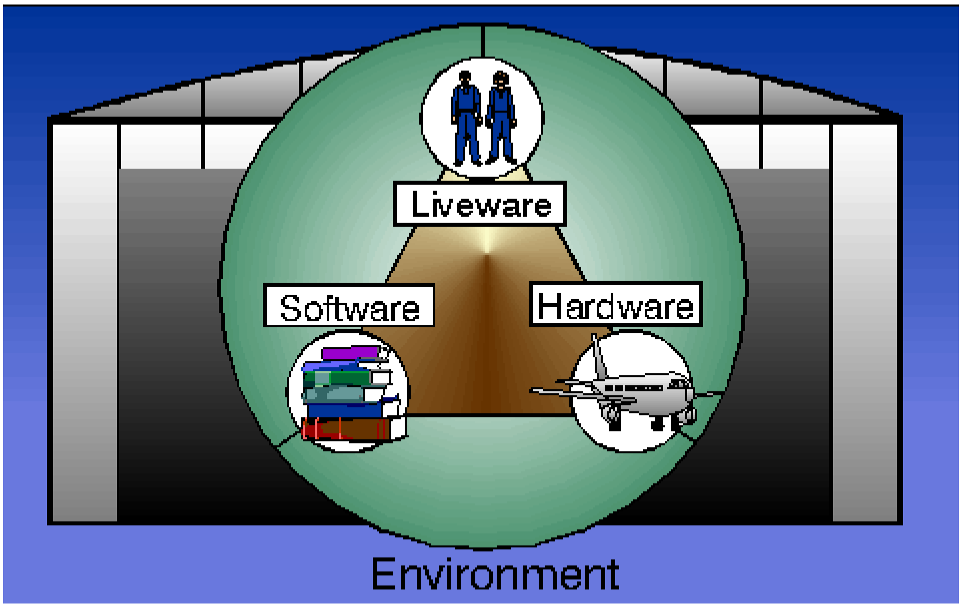


Figure 1-2. The SHEL model.

Human factors practitioners typically concentrate on the interfaces among people and the other system elements. The important point concerning the systems view is that humans cannot be considered to be isolated from other system components. This view is similar to that of ecologists, i.e., that all elements in nature interact. We can't change one aspect of a system without being concerned about its effects on other system elements.

Usability

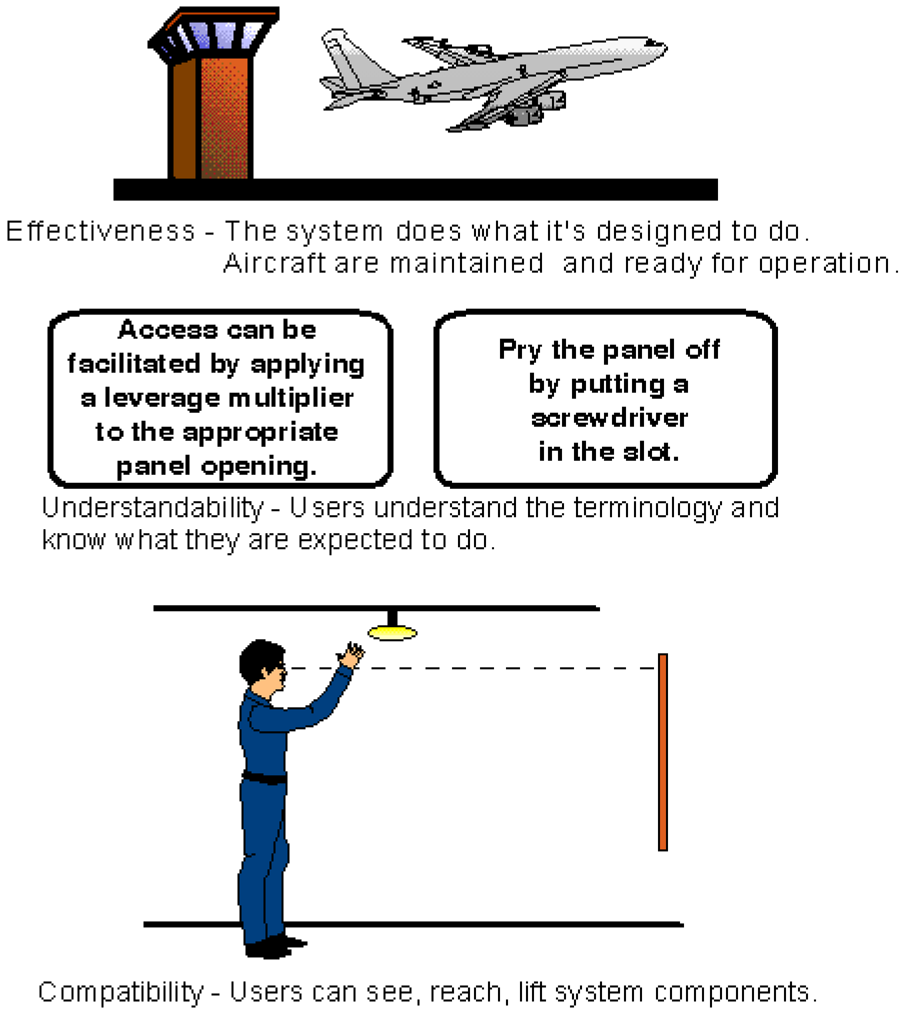


Figure 1-3. Relationship among the three components of usability.

The terms *usable* and *intuitive* describe a desirable characteristic for a system, product, or procedure. The concept of usability has many facets, some of which aren't fully understood or appreciated. There are a number of definitions of *usability*. To put the concept into practical terms, however, consider the following three most important components of usability: compatibility, understandability, and effectiveness.[41] The relationships among these three components are shown in Figure 1-3.

As an example, imagine that we must assess the usability of a workcard designed to guide inspection of the nose gear on a particular aircraft. Let's also assume that the card will have to be read from a distance of one meter.

Compatibility. *Compatibility* refers to the match between a product and the users' physical and perceptual abilities. Users have to be able to see material that must be read, to be able to touch surfaces that must be manipulated, to be able to lift items that have to be physically carried, etc. In the case of our workcard example, all graphics and text must be large enough to be recognized and read from a distance of 1 meter. Also, any colors must provide enough contrast for legibility under the task's lighting conditions.

Understandability. Once we've assured ourselves that a product is compatible with the capabilities of its user population, the next step is to evaluate its understandability. A workcard could be perfectly compatible, but not understandable. Abbreviations, wording, grammar, and other aspects of the workcard might not correspond with the user population's training and experience. Imagine a workcard containing technical medical jargon instead of aviation terms. Even if this card were perfectly legible, aviation maintenance technicians would not be likely to understand it.

Effectiveness. The final component of usability is effectiveness, i.e., the ability of a product or system to support users in their job tasks. This is normally the only facet of usability that interests supervisors and managers. Until the other usability components are verified, however, it's not productive to look at effectiveness. Many factors can cause a compatible and understandable product to be ineffective. For example, the workcard in question could be missing a step. As an extreme example of lack of effectiveness, the workcard might contain no instructions for nose gear inspection or be designed for a different type of aircraft.

User Population

In human factors, we attempt to identify which group, or groups, of people will be using a particular product or system. This group can range from a small number of highly-trained people, such as astronauts, to a country's general population. The group of individuals who will use a system is the *user population* for that system.

It is important to understand who will be using a product because we might have to build in factors to accommodate certain users. As an extreme example, if we're designing (or evaluating) a piece of equipment that will be used by astronauts, we don't really have to worry about accommodating physical disabilities, at least for the present. We also know that all astronauts are highly educated, so we can use technical terms. We can also use technical terms when we're addressing aviation maintenance supervisors and technicians.

The important point about user populations is that we can design a product that performs the exact same function for different user populations. If the characteristics of those user populations are different enough, we might have to design two completely different products.

Vigilance

One category of tasks is so prevalent that it has been given a name: vigilance. Vigilance tasks have been studied by human factors researchers since the second world war.[42] Vigilance tasks involve a human monitoring a visual or auditory display for a particular event. Usually, the event that must be detected is relatively rare, i.e., the human monitor doesn't expect it to happen very often.

Early research into vigilance tasks found that the detection performance of military radar operators decreased very rapidly during their "watch."[43] Subsequent research in a number of different settings has found much the same phenomenon. Within about a half hour of beginning a vigilance task, detection performance drops dramatically and never recovers during the watch. Many other factors such as fatigue cause vigilance performance to decrease more rapidly and to a lower level.

Vigilance tasks are common in the maintenance domain. Any type of repetitive inspection work in which the probability of finding a problem is low qualifies as a vigilance task.[44] Although several methods for doing so have been described, it is quite difficult to mitigate the effects of the loss of sensitivity during a vigil.[45]

Workload

A concept that has prompted much human factors research related to aviation is known as *workload*. While the general idea of workload can apply to both physical and mental aspects of job tasks, mental workload usually gets most of the attention. The basic concept is that people have only so much capacity to perform mental work. If a job task, or set of tasks, exceeds a person's mental capacity, then the workload is excessive and the worker's performance drops.[46]

The necessity for keeping mental workload at acceptable levels is often associated with aircrews, especially in combat situations. NASA has even developed a written rating scale to assess the risk of high workload in cockpits.[47] Although several theories have been advanced to explain workload effects, it isn't clear that the human factors research community has been able to devise a common, objective definition for *workload*.

Since mental workload is not directly meas- urable, research in this area has relied on indirect evidence that a workload is approaching maximum levels.[48] This evidence usually takes the form of worsening performance on certain tasks. The problem with this approach is that it is never clear whether excessive workload or some other effect caused a performance drop.

Regardless of the shortcomings of research in this area, it is clear that humans have a limited capability for performing both mental and physical work. These limits apply to all work domains, including aviation maintenance. It is also clear that people use certain coping mechanisms to deal with high workload: we cope by eliminating all but what we think are the most urgent or important information and tasks.[49] The obvious problem with this coping strategy is that an overloaded technician or inspector might eliminate an important step or fail to identify a problem.

METHODS

There are several general methods used to identify human factors problems and to embed user capabilities and limitations into systems and products. These methods are always used to accomplish one or more of the following tasks:

- To identify user characteristics
- To identify task requirements
- To evaluate jobs, tasks, or products.

"Know thy users" is a fundamental tenet of human factors. The general idea is that if we can describe the users in enough detail and also can identify the requirements of the tasks they are going to perform, we have most of the information we need to design a usable product or system.

The methods described below are mostly not cookbook-type procedures. They can be used to examine people and tasks at a certain level of detail. However, to be fully effective, these methods require specialized knowledge and techniques within the expertise of trained human factors practitioners.

Checklist Evaluation

For a wide range of products, tasks, and systems, checklists exist or can be developed that allow non-experts to identify potential human factors problems. Such checklists are usually based on general human factors principles or on published data related to the area of concern. Checklists were used extensively to evaluate nuclear power plant control rooms following the Three Mile Island accident.[50] Checklists used for *evaluation* are fundamentally different from *operational* checklists which are procedural job performance aids. Table 1-1 is an example of an evaluation checklist.

Properly constructed checklists allow people with little or no human factors experience to compare the attributes of existing or planned systems with acceptable ranges of values for those attributes. Of course, it isn't always possible to judge a system feature's acceptability with a simple comparison. An attribute's acceptability often depends on the system's or product's projected use. Also, rather than simply making a few comparisons with tabled data, multiple-step procedures are sometimes necessary to evaluate products.

Where it's possible to use them, checklists allow for relatively quick evaluation of a large range of variables. Since checklists are already so widespread in the aviation industry, this method probably has a lot of intrinsic appeal and will be more quickly accepted than other, less-familiar methods.

Formal Usability Testing

Usability testing is quite broad. Activities that are considered tests in industrial settings are often little more than demonstrations or quick test drives by end users. While such activities are somewhat valuable, they tend to be unstructured, poorly controlled, and undocumented. Human factors practitioners distinguish between these unstructured "tests" and more formal testing procedures.

Formal usability testing is one of the fastest growing specialty areas in the human factors domain. Several books have been written to help non-specialists plan and conduct various types of usability tests.[51,52] While these books can provide valuable insight into the usability testing process, there are so many subtle effects related to testing and interpreting results of tests that usability testing requires specialized knowledge.

Incident Investigation

Errors in aviation maintenance settings are typically identified when they are linked with property damage, injuries, or both, resulting from some type of incident. Such incidents are formally examined with an incident investigation technique. These techniques are collectively known as "root cause" methods because they attempt to identify and classify all of the proximate causes for a maintenance incident. The new Guide to the HF *Guide* at the beginning of this document is an example of a categorization for human-factors-related incident root causes.

A number of formal root cause incident investigation techniques have been developed within the aviation community. Probably the most well-known technique is the Maintenance Error Decision Aid (MEDA) developed and taught by Boeing[53]. Other aviation-centric root cause incident investigation techniques include Aurora and BASIS. A thorough evaluation of the techniques in existence at the time of this writing (late 1997) has been done by Marx (1997).[54]

All of the existing aviation maintenance error investigation techniques are a combination of checklists and questionnaires, usually combined with interviews and some type of evaluation process. All of these techniques include an embedded database where incident classification information is retained for analysis. Some of the existing techniques also include an analysis module that allows users to perform certain statistical operations on accumulated incident data.

Link Analysis

Most jobs, and even most tasks, aren't static actions occurring in isolation. Real jobs and tasks consist of many individual actions extending over time and space. Link analysis allows us to determine important associations among various task-related elements such as displays, controls, tools, locations, etc.[55]

Link analysis was originally used to help designers lay out control panels, like those in aircraft cockpits and process plants. The technique is easily applied to situations in which we need to layout a computer screen, a workshop, a hangar, or other job components. While users perform job tasks or follow job-related procedures, the analyst(s) notes the locus of each activity. When this is done for a number of tasks and procedures, a statistical picture of important associations emerges. Once these associations are known, we can arrange task elements to minimize the distance users have to move to complete a task.56

A common example of the product of link analysis is the "task triangle" used by kitchen designers. Through link analysis, we know that people move most frequently among the refrigerator, stove, and sink. Since the *links* among these three elements are strong, kitchen designers try to place them at the corners of a fairly small triangle.

Questionnaires and Opinionnaires

A fairly cheap and easy method for gathering human factors information is simply to ask users to give it to us. Written questionnaires and opinionnaires have been used for years to gather data. Adapting them to the human factors domain isn't difficult. A *questionnaire* asks people to fill in factual information or to select from a given set of response choices. Questionnaires are an efficient way of gathering demographic information such as age, gender, educational background, skills, etc.[57]

An *opinionnaire*, on the other hand, asks people to render an opinion about various items. Each item is constructed so that responses can be numerically analyzed. This means that each item consists of what are called "anchored" scales.[58] A scale is simply a numerical progression; for example, a scale could be from 1 to 7. On an anchored scale, a description defines each scale point. We might ask users to rate how easy a tool is to use on a scale of 1 to 7 with the following scale points:

1 = impossible to use

2 = very difficult to use

3 = difficult to use

4 = neither difficult nor easy

5 = easy to use

6 = very easy to use

7 = requires absolutely no skill or effort to use.

Questionnaires and opinionnaires are inexpensive methods of gathering information. Two of the biggest problems with them are a low response rate and the difficulty of developing good *instruments* (this is the technical term for questionnaires and opinionnaires). In a work situation, we have some control over the response rate, since we can give people time off the job to give us the information. People's willingness to respond to questionnaires and opinionnaires is increased when we guarantee the confidentiality of their responses. As an ethical matter, we must ensure that respondents' information is held in strict confidence.

Table 5-3 is a good example of a survey that includes both questionnaire and opinionnaire items.

Task Analysis

Task analysis is so basic to human factors that it can be considered the mother of all human factors techniques. Entire books have been written about task analysis.[59] Task analysis isn't just one method; it is the name given to a range of methods used to determine important task elements.[60] While the actual steps may vary from one task analysis method to another, the intent of each is to describe just what users have to do and know to complete their job tasks.

Ideally, task analysis requires the analyst(s) to interact directly with end users in their job setting. It is very important that task analysis include (1) actual end users (2) in their job setting. The most common source of errors in gathering task information arises from a failure to interact with real end users. It's not good enough to talk with supervisors of end users, with people who know a lot about end users, or with people who used to be end users. For task analysis, we need to gather task information from the people who perform the tasks.

By observing users in their actual job settings, the analyst(s) can gather environmental, organizational, and other job-related information that might have a drastic effect on system design or evaluation. For example, if we see that two people have to view a piece of test equipment simultaneously, then our design must reflect that requirement. Figure 6-1 is an example of the output of one type of task analysis.

There are two weaknesses of task analysis. First, if we're designing a completely new functional system, we might not be able to find any end users who currently perform appropriate tasks. Second, for complex tasks, the sheer amount of task-related information can be difficult to manage.

Fortunately, the first problem doesn't usually have severe practical implications. It's rare for a *completely* new functional task to be formulated because almost all new products and systems combine features from existing systems. Thus, even if there aren't users who perform every task in a new system, there normally are users who each perform some of the new system's tasks. If this is not the case, we have to analyze analogous tasks or rely on expert opinion regarding task requirements. New computer-based simulations can help analyze novel maintenance procedures.[61]

The problem of task complexity has not been solved. The approach that seems most promising is to attack the problem in chunks, grouping tasks in some meaningful fashion. Remember that in order to implement a system, all task-related information has to be present. If we don't get this information with task analysis, we simply have to make it up. Due to system complexity, designers often simply make their best guess as to what users will need. Even the most superficial task analysis usually provides better information than a designer's educated guess.

User Analysis

To effectively design or evaluate the human factors aspects of products or systems, we **must** understand the people who use them. *User analysis* is a category of methods aimed at understanding users. Regardless of the particular method's name, its goal is to identify any user factors that might affect performance on job tasks.

There is a tendency among people who are not trained in human factors to put their own knowledge, background, physical size, and expectations in the place of the users of the system or product they're designing or evaluating. This is a fundamental and serious error. Contrary to popular belief, much of human factors is **not** common sense. We cannot actually put ourselves in the place of real end users. Studies have shown that people aren't very accurate at predicting how they will perform on a given task, much less at predicting how others will perform.[62]

User analysis methods typically gather demographic, physical, and experience information.[63] Demographic information includes age, gender, ethnic background, education, income, etc. Physical information includes size, weight, perceptual, disability, and other data that can help determine the distribution of these characteristics in the user population. Experience factors can include any type of work experience that might be of interest. For example, the amount and type of computer usage is a typical experience factor. Experience factors also include skills such as typing, riveting, etc. Table 1-3 is an example of a checklist used to gather user information.

It's possible to perform user analysis in reverse, i.e., to take an existing or proposed product and analyze it to determine what characteristics users must possess in order to operate the product effectively. The list of requirements is then used in the personnel selection process. For example, if we determine that normal color vision is required to perform an inspection procedure, we can screen people to allow only those with normal color vision to perform that task. Later chapters discuss accommodating, rather than eliminating, users with disabilities.

Walkthrough Evaluation

Checklists are useful for evaluating static system or product elements. However, most aviation maintenance tasks are not static. They require technicians to perform a series of steps, often in a particular sequence, i.e., these job tasks tend to be proceduralized. For such tasks, the walkthrough method can identify human factors problems.[64]

As with some other methods, different names have been used to designate walkthroughs. In essence, a walkthrough consists of having users (or people representative of the user population) walk through a certain set of tasks or steps.[65,66] A trained observer watches the actions the users take and notes those steps or task elements for which a human factors problem exists. Walkthroughs are often recorded on videotape for later examination. An example of a walkthrough checklist is Table 5-5, which is geared toward facility evaluation.

On the plus side, walkthroughs incorporate some of the timing elements of real tasks, as well as a user's interactions with other people. The method is particularly well-suited for highly-proceduralized tasks. It can also be used for crew activities, i.e., for those tasks requiring more than one person. On the minus side, walkthroughs can be time-consuming, can require trained observers, and can require recording equipment. Since walkthroughs must be done with some version of the actual product or system, they are often done on simulators.

READER TASKS

Deciding which tasks are reasonable for maintenance managers and planners is not straightforward. Some tasks clearly should be left to human factors professionals. Most detailed design and evaluation tasks fall in this category. At the same time, supervisors have the knowledge and authority to perform a number of human factors tasks. There is a broad middle ground of tasks for which readers should seek assistance from a trained human factors professional.

The tasks described in this section could fall into any category, depending on complexity, time frame, and other factors. However, these tasks represent those that readers will be asked to perform in the workplace.

Evaluating Jobs and Tasks

Evaluation from a human factors perspective is different from other types of job evaluation. A typical business-related evaluation is to determine the pay level or job title appropriate for a particular job or task. A typical human factors evaluation is to identify and match the physical and psychological elements of a job or task with the people who will be performing it.

Evaluating jobs and tasks from a human factors perspective is a multi-level activity. The most general job and task information is fairly easy to obtain. Supervisors and planners are certainly capable of performing this type of evaluation activity. As an evaluation proceeds to lower and lower levels, the type and amount of information tends to change. The skill and knowledge required to gather this information also tends to increase.

Up to a point, then, it's perfectly reasonable for a supervisor to perform human factors evaluations. At some level of detail, however, it becomes doubtful that a supervisor has either the expertise or impartiality required to continue the evaluation. Probably the best way to deal with job and task evaluation is to become the supervisory member of a team composed of people with various skills and backgrounds, including operations, training, and human factors.

Selecting Products

It seems that more and more commercial products claim to be "ergonomically designed" or "easy to use." A helpful operational reality check occurs when supervisors are asked to approve the purchase of specific products. Unfortunately, most supervisors lack the detailed knowledge, as well as the necessary time, to make informed purchasing decisions from a human factors perspective.

The GUIDELINES section offers tips for selecting products used for aviation maintenance. A number of features can be used to screen products to ensure that they meet at least a minimal level of usability. As with other human factors tasks, however, there are times when evaluating a number of competing products requires either too much time or too many specialized skills.

Choosing Outside Consultants

Because of the specialized knowledge and skills required for many human factors methods, maintenance organizations often employ external consultants. As with other external professionals, the buyer of human factors services is responsible for determining the minimum qualifications of outside consultants. Unlike many other professions, certification for human factors professionals has only recently become available. Thus, organizations tend to rely on "word of mouth" recommendations for qualified individuals or companies.

A few simple guidelines can help supervisors quickly narrow the field of potential outside human factors consultants. With the advent of professional certification, maintenance organizations have an objective way to know that potential consultants meet at least minimal educational and experience criteria.

GUIDELINES

Job and Task Evaluation

There are a number of ways to evaluate jobs and tasks. Which method, or methods, is best depends on the purpose of the evaluation. For example, if a safety issue is related to the evaluation, there are documentation requirements associated with the evaluation. If we're simply trying to decide if any basic human factors principles are violated in a particular task, less-sophisticated observation techniques can be useful.

Many analysis and evaluation techniques are clearly beyond the expertise of most maintenance supervisors and planners. However, the most basic evaluation objectives are to describe the people performing a certain task, the components of the work environment, and the important elements of a task. Much of this is within the scope of what a supervisor or planner might do.

Such information can often be used to spot problems and to suggest solutions. Even when problems and solutions aren't evident, simply having this information available saves time and money when people with greater expertise are brought in to help. When this information is not readily available, it will have to be gathered as part of whatever evaluation process the external expert uses.

The easiest way to gather general user and task information is to combine questionnaires and opinionnaires with direct observation. Checklists help structure these activities while providing a framework for documenting the findings.

These guidelines include six checklists, Tables 1-1 through 1-6, that you can use as a starting point to gather user and task information. Each checklist is oriented toward gathering a particular category of information. You should view these, and, really, **any**, checklist with a certain skepticism. Checklists probably gather more information than you need for some tasks and not enough for others.

Each checklist contains a list of questions you should try to answer during the evaluation. Each checklist's objective is to help you gather and document information so that someone who hasn't visited the user's workplace could get a pretty good idea of what it's like-both physically and task-wise. Don't forget that these are checklists, not scripts. You shouldn't simply carry them into a workplace and expect workers to answer the questions.

As you review Tables 1-1 through 1-6, it should become obvious that some information remains basically the same for all the tasks or jobs you evaluate. For example, most tasks performed on the ramp have the same environmental characteristics: the lighting, climate, outdoor nature of the work, etc., probably do not change much from task to task for all ramp tasks. Since there may be certain groups of jobs and tasks with similar characteristics, documenting the task groups greatly advances any detailed human factors analysis you may want done.

The key concept in any type of information-gathering activity, including those listed here, is **DOCUMENTATION**. Many people view documentation as an unpleasant side effect of business or regulatory policy. Unless the findings of human factors analysis are documented, they are of little value and will eventually be lost. Documentation doesn't necessarily mean paper reports. Photographic or (even better) videotape records are often more valuable than a written version of one person's interpretation of what he or she saw and heard.

The idea behind gathering this type of information is to try to match task and job requirements with the capabilities of the people who will perform them. In this section, we've concentrated on helping you learn how to gather such information. In subsequent chapters, we will describe what you should do with it once you have it.

Table 1-1. Checklist for the general physical environment

1. Does the worker perform tasks indoors, outdoors, or both?

2. If the worker performs any tasks outdoors, does he or she work in all seasons in any kind of weather?

3. Is work done at night, as well as during the day?

4. Does the worker have to wear any kind of protective clothing or safety devices?

5. If the worker works indoors, what type of lighting is used?

6. Are there windows in the workplace? If so, are they small or large? Are they adjacent or in individual workspaces? Which way do they face?

7. What type(s) of lighting is used in the work area?

8. What are some of the representative illumination levels in the work area?

9. What are some representative air temperatures?

10. How is the air temperature controlled?

11. What is the relative humidity in the work area?

12. How is the relative humidity controlled?

13. Are workers generally comfortable in the ambient temperature and humidity, or do they think it's normally too hot, cold, humid, dry, etc.?

14. What is the ambient noise level in the work area?

15. Is any kind of noise "masking" used in the work area? What type?

16. What is the volumetric air flow in the work area? Is it adjustable?

17. What type of floor covering is used in the work area?

18. How many individual workspaces are contained in the work area?

19. How are individual workspaces set off and arranged?

20. Are there any common or break areas in or adjacent to the work areas? If so, where are they in relation to the individual workspaces?

21. Is there any kind of vending and/or cooking equipment in the break area? If not, is there vending and cooking equipment anywhere near the work area?

22. Where are the bathroom facilities and drinking fountains?

23. Are there dressing/locker areas? Where are they located?

24. Is there any type of security lock that must be passed to enter (or leave) the work area? What kind of people get past security, and how do they do so?

25. Where are the supervisory offices or areas located with respect to overall work area and the individual workspaces?

26. Does the arrangement of individual workspaces relate to rank, seniority, or job function or title?

27. Is the work area accessible to individuals with physical handicaps?

Table 1-2. Checklist for individual workspaces

1. How many people occupy each workspace?
2. How is each workspace set off from other workspaces?
3. Are individual workspaces identified as belonging to a particular person?
4. Does more than one person use each workspace, for example on different shifts?
5. Does each workspace have a door that can be closed? Do any workspaces have a door?
6. How much overall floor space is included in each workspace?
7. Do workers feel they have enough room to perform their jobs?
8. What types of furniture and fixtures are included in each workspace?
9. What are the dimensions of the workspace furniture?
10. Do workers have any complaints about the furniture?
11. Do workers sit or stand (or both) to perform their jobs?
12. If workers sit, what type of chair do they use? How many legs does it have? Is it adjustable? If so, how? Does it have rollers? Does it have arms? What is the floor covering in the workspace? Does the chair rest on a hard mat?
13. Does the workspace include a computer display? If so, where is it located? What is the height of the computer's display surface? What is the screen size? Is it color? How many pixels are on the display? How much worksurface area is taken by the display? Can workers adjust its position? Can workers adjust display parameters such as brightness?
14. Does each workspace include one or more input devices? If one device is a keyboard, what type is it? Does it have its own shelf or stand? What other input devices are used?
15. Does each workspace have some type of adjustable task lighting? What kind?
16. What is the typical illumination level at the worker's work surface?
17. Can workers see their co-workers while seated (or standing) at their work area?
18. Can workers converse with their co-workers while seated (or standing) at their work area?
19. Do workers wear headphones or earpieces while in their workspace? If so, can they move out of their workspace while still wearing these devices?
20. Do workers wear a microphone while in their workspace? If so, can they move out of their workspace while still wearing it?

21. Do any workspaces contain special furniture or other devices to accommodate physical, visual, or auditory handicaps?

22. Do workspaces contain storage areas? If so, what type(s) and how much capacity do they have?

Table 1-3. Checklist for demographics

1. What is the proportion of males and females in the worker population?

2. What is the age distribution of the worker population?

3. Is English the first language of all workers? If not, what are the predominant first languages of workers? Are there any workers who cannot read English (or any language)?

4. What is the distribution of cultural backgrounds of workers? Will we have to accommodate workers from other countries?

5. What educational background do we require of workers? If no particular background is required, what is the distribution of educational backgrounds in the worker population? What percentage of workers have graduated from high school?

6. Do we require any skills, such as the ability to type, of workers?

7. Are there any requirements related to the job background of workers?

8. What is the distribution of computer experience in the worker population?

9. Do we test workers for visual capabilities, such as acuity, stereopsis, color vision, etc.?

10. About what proportion of workers wear corrective lenses?

11. Do we test workers for auditory capabilities?

12. Do we screen workers according to any disability criteria?

13. Do we screen workers for any minimum or maximum physical variables, such as height, weight, strength, etc.?

14. Do we presently have any workers with known disabilities? If so, what are they?

Table 1-4. Checklist for task-related elements of a job

1. What are the main categories of tasks these workers perform?

2. About what proportion of workers' time each day is devoted to each type of task?

3. Are similar tasks done in groups, or can different types of tasks be done in any order?

4. Do similar tasks tend to be done at certain times of day or on certain days of the week?

5. Can the worker select the type of task to perform, or is selection externally driven, *e.g.*, by customers?

6. Are workers sensitive to the time it takes to perform certain tasks? If so, which tasks are most time-sensitive and what are their appropriate time targets?

7. Can workers perform their job tasks while they remain in their workspace, or must they move to other work areas?

8. For each major task activity, what are the steps necessary to complete the task?

9. For the task steps mentioned above, what information is essential for completing each step? How should it be depicted?

10. What input and output devices must workers use to interact as they complete tasks in each category?

11. Do workers have to transcribe information from computer to paper, or vice versa? If so, which information?

12. Do workers have to interact with others to perform tasks? If so, for which tasks, with which other people, and how do they interact?

13. Do tasks have to be completed once they are begun, or can they be suspended and then restarted at some later time?

14. Do workers have to use documents or other written information to complete tasks? If so, which documents and what type of other information is necessary?

15. Is any task-related information routinely difficult to obtain or, once obtained, to use?

16. Do workers need access to equipment other than that the company provides? An example might be a worker's need for a calculator.

17. Are there any particular strength requirements for any task? If so, what are they?

18. Do workers have to interact with people who speak different languages? If so, how is this done?

19. Can workers refer certain tasks to supervisors? If so, how is this done?

20. Is the worker's day structured in any particular manner? Can the worker count on doing a particular type of task at a certain time each day?

Table 1-5. Checklist for job-related elements

1. How many people work in the entire work area?

2. What job titles do these people have? What is the distribution?

3. Are workers split into groups according to any particular scheme? If so, what is the scheme?

4. Are the workers unionized?

5. Does job seniority mean anything relative to the tasks being performed? That is, must a person have a certain tenure before being allowed to perform certain tasks?

6. What is the average tenure of workers in this group?

7. Are workers grouped into specialists in particular types of tasks? If so, how are the tasks defined?

8. Are workers free to "bid" on other jobs within the group or company?

9. How are workers compensated for their work, e.g., hourly vs. salaried, overtime pay, etc.?

10. Are workers given any incentives, financial or otherwise, to increase their job performance? If so, what are those incentives?

11. What measures are used to evaluate worker performance?

12. Is there a "promotion from within (or without)" policy?

13. Do workers have to meet particular job performance measures each day? If so, what are they?

14. How are workers scheduled to work?

15. Are workers monitored while they are working?

16. How much training are workers given before they begin working?

17. How much experience must workers have before they are considered fully proficient on the system?

18. Are workers given any recurrent training?

19. What is the most difficult aspect of the present system to learn?

20. What is the turnover rate among workers?

21. How many errors do typical workers commit per unit time (hour, day, etc.)?

22. How much does it cost to process each "transaction"?

23. How long does it take to process each "transaction"?

24. How much does it cost to correct an error?

25. What is the most frequent worker complaint regarding the work?

26. What is the most frequent worker complaint regarding the system?

Table 1-6. Checklist for elements related to a specific task

1. How many workers are required to perform this task?

2. What are these workers' job titles?

3. If more than one worker is required to perform the task, do they work simultaneously or one at a time?

4. Do workers performing this task have to communicate with other people at various points?

5. How much time does the overall task require?

6. Are the people who perform the task evaluated or judged on the amount of time required to complete it?

7. What individual steps are required for the task?

8. Who performs each step?

9. What tools are required for each step?

10. Where must workers go to obtain tools? How do they obtain tools?

11. Is there a written procedure that must be followed for each step?

12. If procedures are used, are they sign-off procedures? Single or double sign-off?

13. For each step, how does the worker know that the step has been completed?

14. For each step, what documents must the worker have access to?

15. Are written materials other than procedures required for a particular step or for the overall task? Which ones? Where are they stored?

16. How long does it take to perform each step?

17. Are there any hazards inherent in this task?

18. What measures are used to evaluate worker performance?

19. Once the task is completed, is the work inspected? By whom?

20. What time of day is this task usually performed?

21. Are workers monitored while they are working? By whom?

22. Is this task scheduled or on-demand?
23. If the task is on-demand, what is its nominal priority?
24. At what time of day is this task usually performed?
25. Do workers consider this task particularly difficult or bothersome?
26. Is any prestige associated with performing this task? If so, describe it.

Product Selection

Later chapters in the *Guide* discuss the advantages of and problems associated with products that might be used in the aviation maintenance workplace, e.g., back belts. In this chapter, we're addressing the general idea of using human factors criteria to select a product. Vendors are a good source of technical information about their products (and about competing products). Vendors' claims of "usability," however, tend to be at least slightly biased.

Table 1-7. Criteria for selecting products

Consistency

It is easier for workers to learn and use products with a consistent user-product interface. If workers already use products that are functionally similar to the proposed (new) products, there are essentially two human factors tasks:

1. Ensure that the new product's user interface is consistent with the existing product's,
or

2. Change out the existing products so that all user interfaces are consistent with the new product.

Compatibility

Any products introduced into the workplace need to be compatible with the people who are going to use them. New products must accommodate the physical size and strength of users, as well as any workplace sensory demands, such as noise, lighting, etc. Products must also be compatible with any protective clothing workers wear, such as gloves, goggles, etc.

Understandability

All the terminology, labeling, abbreviations, acronyms, instructions, etc., that are part of the new product must fit with the experience and expectations of the people who will use it. It is not appropriate to force users to learn an entirely new set of terms to use a new product.

Safety

Any new product should be subject to a safety evaluation undertaken by people familiar with the aviation maintenance environment. This topic is covered more fully in Chapter 3.

Error Handling

A product that depends on perfect performance by workers will eventually fail. Since all humans commit errors, new products should be evaluated on the basis of how they handle the inevitable errors that occur. How easy is it to correct an error? What are the consequences of particular types of errors?

Functional Appropriateness

> It is easy to get carried away with technological capabilities and to forget what a product is really supposed to do. New products sometimes support a functional capability that is not only unnecessary and impractical from a business perspective but may also be potentially harmful to workers.

It sometimes happens that a purchasing decision is easy because one product is so functionally superior to all its competitors. It is much more common that several products are able to do the job, and your decision must be based on other factors. Table 1-7 contains a list of criteria that you can use to judge products.

The criteria in Table 1-7 probably won't help you make subtle distinctions among products closely matched for usability. They will help you identify major human factors problems with individual products. They can also help you rank multiple products from most capable to least capable of performing the required tasks.

In cases where the product's cost or the consequences of a poor selection justify it, it is certainly appropriate to perform a formal usability test on new products. Formal testing can identify subtle problems with and differences among products. Even if a formal, structured usability test is not required, a formal human factors evaluation by a trained practitioner might be appropriate.

Consultant Selection

Selecting a consultant can be a confusing process. Many factors potentially affect a decision to hire an outside expert, and many more affect the selection decision. Aside from obvious considerations such as a consultant's cost and availability, there are three factors you should consider when selecting a human factors consultant: qualifications, experience, and demonstrated competence. Table 1-8 summarizes the relevant criteria regarding a human factors consultant's qualifications and experience. These criteria are described below.

Qualifications

In the United States, there is only one professional organization dedicated to human factors. As of the end of 1997, the Human Factors and Ergonomics Society (formerly the Human Factors Society) had over 5000 persons who claimed some level of membership. Slightly less than 3000 people qualify for full membership. Full membership requires an approved bachelor's degree and five years of work experience, for which up to four years of academic work can be substituted.

Table 1-8. Criteria for selecting human factors consultants

Academic/ Professional Qualifications

> Full membership in the Human Factors and Ergonomics Society or its international counterpart the International Ergonomics Association
>
> Advanced degree in Human Factors or a related discipline such as Engineering Psychology, Experimental Psychology, Systems Engineering, Physiology, etc.

Experience

Minimum:

At least 5 years of full-time human factors work, preferably in a non-research setting. Academic researchers are acceptable as consultants for extremely specific issues within their range of expertise.

Demonstrated experience with the type of human factors work to be performed. It is desirable that such work have been performed in at least 2 different domains.

Preferred:

At least 7 years of full-time human factors work in a non-research setting. (See Certification and Licensing)

Demonstrated experience with the type of human factors work to be performed. Experience over a variety of domains.

While the HFES *does not* certify or otherwise vouch for the credentials of its members, it does publish a Directory of Human Factors and Ergonomics Consultants containing certain background information for those members who are (1) full members of HFES and (2) willing to pay for a listing in the Directory.

Within the HFES, there are 17 Technical Groups (TGs) that are subgroups of members with specific technical interests. The topical interests of TGs include aging, training, consumer products, aviation, forensics, and organizational management. It is not necessary for a member to belong to a TG.

Certification and Licensing

Presently, human factors and ergonomics practitioners do not have to be either certified or licensed. Until recently, there were very few organizations that provided any type of human factors or ergonomics certification, even if a practitioner wanted to become certified. The Human Factors and Ergonomics Society *does not* certify practitioners. Within the past few years, a few voluntary certification bodies have been established. The largest of the certification groups is the Board of Certification in Professional Ergonomics. At the time of this writing (late 1997) 725 people have received full certification from the BCPE and 54 more have achieved associate status.

In order to be certified, applicants to the BCPE must meet the following criteria:

- At least a masters degree in human factors or a related discipline from an accredited institution
- At least 7 years of full-time work in human factors *practice* (not research)
- Provide descriptions of at least two projects that require expertise in *each* of the areas of analysis, design, and evaluation/testing
- Provide work products that demonstrate expertise in design *and* either analysis or evaluation/testing.

Certification, from the BCPE or any other organization, is not a guarantee of ability or knowledge. Certification *does not* imply that the certificant is capable of doing the work you need to do, nor does the absence of certification mean that a consultant will not be able to help you. You should use certification as one of a number of factors upon which to base your decision to hire a consultant. As we note below, ask for and check out references before hiring any outside human factors consultant.

Experience

While certification vouches that an individual has the required number of years of experience, it doesn't specify the *type* of experience an individual may have. Since human factors is such a broad discipline, it's possible that a particular individual, even a certified professional, might not have experience with the particular type of work you need to have done.

There seem to be two schools of thought regarding what constitutes appropriate experience. One school holds that it is necessary for human factors consultants to have experience working in a particular domain such as aviation maintenance. The other school maintains that since human factors skills are so broad, experience in a particular domain is of little value; in fact, ignorance of a particular domain may be an asset because the consultant can bring a fresh perspective to problems.

Even consultants who are initially naive regarding a particular domain become well-versed in that domain during the course of their work. This is simply a by-product of the human factors perspective, which is to understand the users and tasks related to any performance issue. There is no doubt that constant immersion in a particular domain causes people to become less sensitive to that domain's potential problems. A fresh perspective is often a tremendous asset.

The most practical guidance regarding evaluating a consultant's experience is to look for someone with real-life experience performing the types of tasks you expect the consultant to perform. Familiarity with the tasks or work environment the consultant is expected to evaluate is of less practical importance. For example, suppose that you need a consultant to analyze certain tasks related to a piece of automated test equipment and then to recommend a user interface for that equipment. Desirable experience for the consultant would be a history of analyzing user requirements, specifying functional features, and designing user interfaces in a variety of domains.

The real value that a human factors consultant brings to any problem depends on two components:

- specialized knowledge
- broad experience.

Specialized knowledge refers to the consultant's knowledge of how to apply human factors techniques that identify and embed user characteristics into your systems. Specialized knowledge of a particular domain might be helpful, but is far less important. Think of a human factors consultant as a catalyst for extracting the domain knowledge that already exists in your users and workers. Both your workers and yourself know more about your job than any outside consultant.

Broad experience simply recognizes the fact that the same human factors issues arise over and over, regardless of the particular domain. Experience in a number of different domains increases the chance that the consultant will have seen many ways of addressing issues in your domain. There really isn't any substitute for hands-on experience over a range of industries and over a span of time.

Verified Competence

Even with the best qualifications and experience, an individual consultant might not be "right" for a particular job. In any field, someone who looks good on paper might be unable to work in a certain situation. As a final screening criterion, the person hiring a consultant should ask to see examples of previous work and a list of references. References should include people in other companies for whom the consultant has worked.

Ask for references for the person (or people) who will actually be doing your work. Do not assume that a consulting company will assign specific people to do your work. Find out who will be doing the work and ask for their references, specifically.

Call the references. Ask the references to describe the candidate's expertise, efficiency, and personality. Ask if they were pleased with the work the candidate performed. Ask if they feel they got value for their money. Ask anything else you'd like to know to be comfortable hiring the consultant. People who hire consultants are sensitive to the problems inherent in doing so and are usually happy to provide whatever help they can to others who are considering hiring the consultants they have used. A few phone calls can save a lot of wasted time and money.

WHERE TO GET HELP

There are several sources of help for human factors issues or problems. The Human Factors and Ergonomics Society (HFES) is usually a good source of general human factors information. They produce publications and videos related to general human factors issues including an annual Directory of Consultants. The HFES is located in California, at the address below:

Human Factors and Ergonomics Society

PO Box 1369

Santa Monica, CA 90406

Phone: (310) 394-1811

Fax: (310) 394-2410

Web site: http://hfes.org

Email: hfes@compuserve.com

The Board of Certification in Professional Ergonomics is the largest of the certification organizations for human factors practitioners. They produce a list of certificants, but do not recommend individuals to help with particular problems. They are located in Washington state at the following address:

Board of Certification in Professional Ergonomics

PO Box 2811

Bellingham, WA 98227

Phone: (360) 671-7601

Fax: (360) 671-7681

Web site: http://www.bcpe.org

Email: bcpehq@aol.com

For help with specific human factors problems, a good source of information is the Office of Aviation Medicine (AAM) in the FAA. The AAM sponsored the development of this *Guide*. It also sponsors a good deal of human factors research and development each year. Since part of the charter of the FAA is to help the commercial airline industry address human factors problems, the AAM is a good starting point for inquiries related to such problems. Contact the AAM at the following address:

Ms. Jean Watson

Office of Aviation Medicine

Federal Aviation Administration

800 Independence Ave., SW

Washington, DC 20591

Phone: (202) 267-8393

The Crew System Ergonomics Information Analysis Center (CSERIAC) is a Department of Defense Information Analysis Center located at Wright-Patterson Air Force Base, Ohio. Managed by the University of Dayton Research Institute, the CSERIAC will conduct detailed literature searches for specific human factors topics. It also produces a number of pre-researched reports, which are for sale.

CSERIAC Program Office

AL/CFH/CSERIAC Bldg 248

2255 H Street

Wright-Patterson AFB, OH 45433

Phone: (513)255-4842

Fax: (513)255-4823

FURTHER READING

The documents listed below contain information pertaining to human factors. They may or may not have been referred to in the chapter. These citations are grouped under general topics to make finding particular information easier. Within each topic area, all references are arranged alphabetically.

Non-Technical Books

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Merrill Publishing Company.

Tables and Charts

NASA (1978). *Anthropometric source book, Volumes I-III* (NASA RP-1024). Washington, DC: US Government Printing Office.

Tilley, A.R. (1993). *The measure of man and woman-Human factors in design*. New York, NY: The Whitney Library of Design.

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Periodicals

Applied Ergonomics, IPC Business Press. Oriented toward applied problems in business and industry.

Ergonomics, The Ergonomics Society and The International Ergonomics Association. Emphasizes objective research. Oriented toward professional human factors practitioners.

Ergonomics in Design, The Human Factors and Ergonomics Society. Emphasizes applied issues in business and industry. Aimed at non-human factors professionals.

Human Factors, The Human Factors and Ergonomics Society. Very research-oriented. Directed toward professional human factors practitioners.

Interactions, Association for Computing Machinery. Addresses applied issues related to computers, programming, etc. Aimed at non-human factors professionals.

SIGCHI Bulletin, Special Interest Group on Computer-Human Interaction, Association for Computing Machinery. Addresses more abstract issues than *Interactions*, but aimed at generally the same audience.

Miscellaneous

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EXAMPLE SCENARIOS

The scenarios presented below represent some typical kinds of human factors tasks that one can expect to encounter in the workplace. The purpose of including these scenarios in the *Guide* is to demonstrate how the authors foresee the document being used. For each scenario, we describe how the issues raised in the scenario can be resolved. There is usually more than one way to approach these issues, so responses given below represent only one path users of the *Guide* might take.

As a general rule, always start to look for information by using the Search function. There will be instances that you already know where required information is located. However, unless you frequently use specific sections of the *Guide*, you might miss information pertaining to the same issue located in more than one chapter. The Search will allow you to quickly search all chapters simultaneously.

Scenario 1 - Evaluating claims of "ergonomic" design

A vendor has developed a new eddy current crack detector. The vendor claims that this new device has been ergonomically designed so that its output is easier to interpret than that of existing devices. The cost of the new device is only marginally higher than for existing eddy current detectors.

Issues

1. A key concept in human factors is the user population. How will you identify the user population for the new device?
2. Other than cost, what aspects of the new device should you evaluate from a human factors perspective?
3. How will you determine whether the vendor's claims are true?

Responses

1. The concept of *user population* is described in earlier. Essentially, a user population consists of those individuals who are going to use a particular product or system. In the case of the eddy current crack detector, the user population is those technicians who will use the device. Beyond simply identifying the user population, you might also want to define those characteristics of users that could affect your evaluation of the new device. This topic is covered in "User Analysis."

2. In this scenario, we are dealing with a product evaluation and selection task. In the GUIDELINES section, product selection is addressed. The human factors criteria related to product selection are contained in Table 1-7.

3. This is really the main issue of the scenario. It is also the central question in all product purchase decisions. Does the product do what the vendor says it does? This question has no "right" answer. There are a number of methods that can be used to evaluate users' performance with a particular product. The chapter contains descriptions of four evaluation techniques. These are checklist evaluation, walkthrough evaluation, questionnaires and opinionnaires, and formal usability testing.

The two methods that seem most appropriate in this scenario are walkthrough evaluation and formal usability testing. It is possible that technicians or managers who are already familiar with eddy current crack detection tasks could devise a reasonable walkthrough script. Formal usability testing almost certainly requires the services of a trained human factors professional.

Scenario 2 - Workstation design

You've been asked to design a new mobile workstation that can be used to make various hydraulic checks. The workstation has to be used on the ramp and inside the hangar.

Issues

1. Do you need the help of a human factors professional for this project?
2. Regardless of your response to the first question, let's assume that you decide to hire an outside consultant. What sorts of qualifications would you look for in such an individual?
3. How will you determine the characteristics of the physical environment in which this workstation will be used?

Responses

1. This scenario presents a detailed design task. In the introductory text for the READER TASKS section of this chapter, we state that "most detailed design and evaluation tasks" require the expertise of a human factors professional. Detailed design is **not** one of the tasks for which we provide guidelines. It is not clear from the way the issue is stated in the scenario whether an outside consultant is needed. It is possible that in-house human factors expertise will be present in some maintenance organizations. If this is not the case, such expertise should be obtained outside the organization.

2. This issue clarifies the question of whether the human factors expertise comes from inside or outside the organization. We are assuming that we have to hire an outside human factors consultant. In such cases, Table 1-8 provides a fairly complete description of the qualifications one should require of such individuals.

3. Characterizing the physical environment in which a product will be used is a common human factors task. In the GUIDELINES section we provide a series of tables that help you determine a number of characteristics related to particular jobs and tasks. Specifically, Table 1-1 addresses the physical environment for tasks.

As with all of the information in this *Guide*, some of the items in Table 1-1 might not apply to every situation. Therefore, you should use Table 1-1 as a template and select only those items that apply to the product or task you are evaluating. For example, item 22 in Table 1-1 relates to the proximity of bathroom and drinking facilities. This may be of no interest whatsoever when evaluating the eddy current crack detector. On the other hand, item 27, which relates to accessibility for handicapped users, might be directly relevant. Pick and choose for each situation.

Scenario 3 - Evaluating operational problems

You've received a number of complaints from the Operations Department regarding a recurring hydraulic leak in a particular type of aircraft. You've asked your technicians and inspectors about this problem. They've told you that these leaks occur in a fitting that is "hidden," making it particularly difficult to tighten and inspect.

Issues

1. How will you determine whether this fitting is actually the problem causing the recurring leaks?
2. How will you go about evaluating the accessibility of the fitting?
3. How will you determine just what technicians and inspectors have to do to tighten and inspect the fitting?
4. How can you determine whether factors other than the fitting contribute to this problem?

Responses

1. According to the scenario description, you've already taken the first step to resolve this issue. By talking to the technicians and inspectors who perform the task of tightening the fitting, you have taken advantage of their knowledge and experience. While addressing the remaining issues in this scenario, you will gather enough information to say, with a high degree of certainty, whether the fitting itself is the cause of the recurring leak.

2. The most appropriate method for evaluating the accessibility of the fitting is task analysis, which is described in the METHODS section. In the GUIDELINES section, the "Job and Task Evaluation" subsection contains a series of checklists from which you can extract enough items to examine the accessibility issue. Essentially, you're going to watch one or more technician tighten the fitting in question.

3. This is simply a continuation of the previous issue. You should conduct a task analysis addressing the procedures related to the fitting in question. Specifically, Table 1-6 contains items that should help you identify each of the steps leading up to and including tightening this fitting.

4. It's often the case that a troublesome component is only one aspect of a maintenance problem. For example, procedures might be inadequate; certain tasks might require more, or fewer, people than are allocated to them; inappropriate tools might be used, etc. As part of the task analysis, you should look at various job-, task-, and workspace-related elements. These topics are covered in Tables 1-5, 1-4, and 1-2, respectively.

Scenario 4 - Evaluating new technology

You've been to a trade show and seen a really neat automated NDI system. After it is set in place on a wing, or other large surface, it searches for rivets, tests each one it finds, and shows the raw test scan on a display. A technician simply monitors the display and decides whether an imperfection exists in the rivet. If the technician decides that the rivet has (or might have) a problem, he or she can cause the system to "mark" the rivet with ink. This system can do an entire wing surface in about 6 hours.

Issues

1. Would you expect the technician's job to be easier with this system than with the present method of testing each rivet? Why or why not?
2. What is likely to happen to the technician's performance detecting rivet defects over the 6-hour period? Why?
3. How might you improve the system from a human factors perspective?

Responses

1. This is sort of a trick question. Since we don't tell you how technicians must presently perform this job, it's hard to say whether the new way will be easier. However, the intent of the question is to get you to look beyond the novelty of the equipment and to focus on what a user would actually have to do. Earlier, we discuss the concept of taking a "systems" approach to maintenance. In this view of things, people are one component in the overall maintenance system, which includes hardware, software, and the operational environment. A correct response to this question is that the new method might be easier or more difficult than the existing method, depending on what users have to know and do.

2. The way we've described the technician's tasks using the new inspection device, you should expect his or her performance to deteriorate rapidly and remain low for most of the 6-hour period. The reason for this performance decrement is that the task, as we've described it, is a classic vigilance task. Earlier, we describe the concept of vigilance and how human performance rapidly deteriorates during vigilance tasks.

3. There are a couple of obvious improvements that can be made to this system from a human factors perspective. For example, the vigilance portion of the technician's task could be automated so the equipment could alert the technician when it finds a suspect rivet. From our description of this device, you might wonder how the technician would be able to tell which rivets have been tested. Remember, only the bad rivets are marked. A better idea would be to mark all the rivets that have been tested, but to mark the bad rivets so they look different from the good rivets.

There is nothing in this chapter that would tell you what these obvious improvements might be. We've taken the position that a trained human factors practitioner should address detailed design questions. Some readers might come up with these, or other, improvements based on their intuition and experience. However, we haven't included enough information in the *Guide* to support design tasks.

Scenario 5 - Evaluating competing products

Three vendors have developed computer-based systems for displaying workcards and allowing technicians and inspectors to enter data directly into the computer. You would like to evaluate all of the products for the usability of their human interface, but, for the sake of consistency, you want to buy only one.

Issues

1. How would you go about devising an objective test to compare the three products?
2. Is this test something you can (or should) develop without any outside help?
3. Who would you ask to use the products in the test? Why?

Responses

1. This is a fairly common product selection scenario in which we want to compare the overall performance of three competing products. The "Product Selection" subsection contains a discussion of how to approach product selection. However, that discussion doesn't get into the details of how to devise a test. Instead, it suggests that you should enlist the services of a human factors professional if you want to do a formal usability test. It might be possible to select the most appropriate product by simply comparing them using the criteria given in Table 1-7.

Another possibility is to use the information regarding some of the methods used to gather usability information. The discussion of "Questionnaires and Opinionnaires" is especially relevant to this scenario. You could select a sample of potential users and allow them to perform a series of tasks using each candidate system. After they use each system, they could fill out an opinionnaire related to the system's ease of use. This method might provide enough information for you to make a purchase decision. However, in order to make a decision that will affect all future purchases, you might still want to conduct a formal usability test. The *Guide* doesn't provide enough information to allow you to develop such a test without outside help.

2. The short answer is, "No." Unless you elect to do something like the opinionnaire test described above, you should not attempt to devise a formal usability test without the assistance of a human factors professional. The term "outside help" is a bit misleading. In fact, the help you need might reside within your organization, or elsewhere in the company. The discussion on "Formal Usability Testing" hopefully makes it clear that such testing requires specialized knowledge.

3. This is the same issue as the "user population" question raised in the first scenario. The answer is the same-you would use people who have the same characteristics as those who will use the systems in a production environment. The reason is, you want to know how actual users will interact with the candidate systems.

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